Section: Original Investigation

Article Title: The Reliability of Individualized Load-Velocity Profiles

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ABSTRACT

Purpose: This study examined the reliability of peak velocity (PV), mean propulsive velocity (MPV), and mean velocity (MV) in the development of load-velocity profiles (LVP) in the full depth free-weight back squat performed with maximal concentric effort. **Methods:** Eighteen resistance-trained men performed a baseline one-repetition maximum (1RM) back squat trial and three subsequent 1RM trials used for reliability analyses, with 48-hours interval between trials. 1RM trials comprised lifts from six relative loads including 20, 40, 60, 80, 90, and 100% 1RM. Individualized LVPs for PV, MPV, or MV were derived from loads that were highly reliable based on the following criteria: intra-class correlation coefficient (ICC) >0.70, coefficient of variation (CV) ≤10%, and Cohen's *d* effect size (ES) <0.60. **Results:** PV was highly reliable at all six loads. Importantly, MPV and MV were highly reliable at 20, 40, 60, 80 and 90% but not 100% 1RM (MPV: ICC=0.66, CV=18.0%, ES=0.10, standard error of the estimate [SEM]=0.04m·s^{-1}; MV: ICC=0.55, CV=19.4%, ES=0.08, SEM=0.04m·s^{-1}). When considering the reliable ranges, almost perfect correlations were observed for LVPs derived from $PV_{20\text{-}100\%}$ (r=0.91-0.93), $MPV_{20\text{-}90\%}$ (r=0.92-0.94) and $MV_{20\text{-}90\%}$ (r=0.94-0.95). Furthermore, the LVPs were not significantly different (p>0.05) between trials, movement velocities, or between linear regression versus second order polynomial fits. **Conclusions:** $PV_{20\text{-}100\%}$, $MPV_{20\text{-}90\%}$, and $MV_{20\text{-}90\%}$ are reliable and can be utilized to develop LVPs using linear regression. Conceptually, LVPs can be used to monitor changes in movement velocity and employed as a method for adjusting sessional training loads according to daily readiness.

INTRODUCTION

Resistance training intensity is typically derived from a percentage of an actual or estimated one-repetition maximum (1RM) assessment.[1] Once a 1RM load is determined, a strength coach can periodize the relative intensity of the training sessions to maximize adaptation and allow for recovery.[2] Although this method is relatively simple and requires no monitoring equipment, an athlete's maximal strength can increase rapidly,[3] suggesting that continued prescription of relative loads from a baseline 1RM could compromise adaptation. Alternatively, an athlete who may be excessively fatigued for a prescribed training session is still required to lift a load, which may exacerbate fatigue and prolong recovery time. Therefore, it is necessary to establish a more precise and less-demanding method of monitoring athlete's training that can be used to modify exercise intensity when necessary.

Research has demonstrated an inverse linear relationship exists between load and velocity (load-velocity profile [LVP]), meaning that if maximal effort is given for the concentric phase of a lift, heavier loads cannot be lifted with the same velocity as lighter loads.[4-8] Furthermore, if maximal concentric effort is provided within a training set for a consistent range of motion, velocity will decline as concentric muscular fatigue ensues.[9] Currently, it is not known what occurs to movement velocity between training sessions when an athlete is fatigued in non-ballistic type exercises such as the barbell back squat. It is hypothesized that when an athlete is fatigued they may perform repetitions with reduced movement velocity compared to their non-fatigued velocity. However, in order to monitor training induced changes in movement velocity, the reliability of movement velocity used to develop LVPs needs to be established. This is critical for a coach who needs to differentiate between true changes in their athlete's movement velocity as a result of fatigue or training induced adaptation, and not just the typical error observed between training sessions.

Previous studies have established LVPs for the prone pull-up, bench press, leg press, half squat, and full squat exercises.[6,10,11] The LVP regression equations reported by Conceição et al.[10] and Gonzalez-Badillo[6] were obtained from the group mean of 15 and 56 subjects, respectively. It is important to discern that different athletes can produce unique movement velocities based on individual characteristics such as their limb biomechanics and expression of fibre types.[12,13] Therefore group mean LVP equations may not be appropriate for accurate monitoring of individual athletes who generate faster or slower movement velocities than the group mean. Notably, Conceição et al.[10] and Gonzalez-Badillo[6] did not report the baseline test/re-test reliability of movement velocity used to develop the LVPs of the subjects. Therefore, it is difficult to establish the exact significance of their findings since the typical variation in movement velocity between testing sessions was not reported for their subjects in a non-fatigued state. However, a key finding from these studies was that LVPs are exercise specific. With this in mind, it is important to note that Conceição et al.[10] and Gonzalez-Badillo and Sanchez-Medina[6] had subjects perform repetitions on a weight machine or Smith machine with a 3-4 second pause between the eccentric and concentric phase of the maximal effort concentric contractions (pause method). Conceição et al.[10] suggest the pause between eccentric and concentric phases can minimize measurement error by removing the influence of the stretch shortening cycle (SSC) from the concentric contraction. Although the findings of the two aforementioned studies are valuable, it is possible that their results are not ecologically valid with free-weight exercises utilizing the SSC that also involve vertical and some horizontal barbell movements.[14] This is important to discern since exercises performed in a free-weight manner utilizing the SSC are more popular among athletes and have been shown to have greater transfer of training effects to sports performance compared to concentric only contractions, particularly in more complex multi-joint exercises.[15,16] While studies examining the LVP to monitor training appear promising, no previous study has assessed the reliability of movement velocity used in LVPs when individuals are in a non-fatigued state across multiple assessments for a free-weight squat exercise.

Three methods are often employed to quantify concentric movement velocity, which include peak velocity (PV), mean propulsive velocity (MPV), and mean velocity (MV).[2,6,10] MPV has recently been popularized and has been utilized in the aforementioned load-velocity profiling studies for the pull-up, bench press, leg press, half squat, and full squat exercises.[6,10,11] In addition to utilizing MPV, Gonzalez-Badillo and Sanchez-Medina[6] employed second-order polynomial regression over linear regression to improve the strength of the correlations for the LVPs. Despite the continued use of MPV, many velocity measurement tools quantify PV and MV but do not report MPV. Thus, the use of MPV and polynomial regression equations may add an unnecessary level of complexity to data analysis for strength and conditioning practitioners. However, it is not known whether MPV or the use of polynomial regression is necessary to develop reliable LVPs in free-weight exercises. Therefore, the purpose of this study was to investigate the reliability of PV, MPV and MV to develop LVPs and determine whether more complex polynomial regression is necessary to improve the relationship between load and velocity in a free-weight exercise.

METHODS

Subjects

Eighteen resistance-trained male volunteers participated in this study (age: 27.2 ± 4.1 y, height: 180.2 ± 6.1 cm, body mass: 80.5 ± 8.7-kg). Subjects were able to perform the full back squat with at least 1.5 times their body mass, had at least 6 months of resistance training experience, were familiarized with the 1RM assessment and were free from musculoskeletal injuries. Each subject was provided with information regarding the study, completed a medical questionnaire and gave written informed consent prior to volunteering for this study in accordance with the ethical requirements of Edith Cowan University Human Research Ethics

Committee and the Code of Ethics of the World Medical Association (Declaration of Helsinki). Subjects height, body mass, squat depth (knee angle) and barbell rack height were recorded, which was followed by a baseline one-repetition maximum (1RM) assessment. Peak knee flexion angle at the bottom of the squat, average 1RM back squat, and 1RM to body mass ratio were: 122.6 ± 11.4°, 142.3 ± 28.3-kg, and 1.74 ± 0.21, respectively.

Experimental Design

The present study incorporated three 1RM trials to investigate the reliability of peak velocity (PV), mean propulsive velocity (MPV), and mean velocity (MV) at 20, 40, 60, 80, 90 and 100% 1RM in the full depth back squat exercise. Subjects were required to wear the same footwear to each session and had their own testing sessions conducted at the same time of day on every occasion. No lifting belts or straps were used for this study. They reported to the laboratory on four occasions, which included a familiarization session (baseline 1RM assessment) and three subsequent 1RM trials with 48 hours between sessions. Previous research has shown that 24 or 48 hours is sufficient time for individuals to recover from a 1RM back squat.[4,17] The baseline 1RM assessment was performed so that accurate relative intensities from 1RM could be lifted in the remaining three 1RM trials. Values of PV, MPV and MV were collected from all repetitions in the three 1RM trials and used for the reliability analysis.

Experimental Procedure

Prior to each 1RM assessment the subjects performed a warm up protocol comprising of cycling on an ergometer for five minutes (Monark 828E cycle ergometer; Vansbro, Dalarna, Sweden) at 60 revolutions per minute and 60W, dynamic stretching for three minutes, followed by the 1RM assessment. 1RM assessments consisted of five sets pertaining to 20% (3-repetitions), 40% (3-repetitions), 60% (3-repetitions), 80% (1-repetition), and 90% (1-repetition), which was followed by the first 1RM attempt.[4] The highest MV value of the three repetitions performed at 20, 40, and 60% 1RM, for each set was chosen for reliability analysis.

Five 1RM attempts were allowed with three minutes passive recovery permitted between sets. All repetitions were performed in a custom-built power cage (Fitness Technology, Adelaide, Australia) using a 20 kg barbell (Eleiko®; Halmstad, Sweden). Between 0.5 and 2.5 kg was added to the barbell weight after successful 1RM attempts until no further weight could be lifted with correct technique. For each repetition, subjects had to achieve a pre-determined squat depth established from their familiarization session. This was completed by measuring the knee angle at the bottom of the squat using a goniometer, which corresponded to a specific barbell displacement depth that was recorded on a LabVIEW analysis program (National Instruments, version 14.0).[4,18-20] Each repetition was monitored by visual displacement curves to ensure the equivalent barbell depth was maintained. Each repetition required subjects to descend (eccentric phase) in a self-selected controlled manner until full knee flexion was achieved then immediately perform the ascending phase (concentric phase) as rapidly as possible while the subjects feet remained in constant contact with the floor and the barbell in constant contact with the superior aspect of the trapezius muscle.

Data Acquisition

Four fixed position transducers (Celesco PT5A-250; Chatsworth, California, USA) monitored the barbell displacement and velocity data, which was then collected via a BNC-2090 interface box with an analogue-to-digital card (NI-6014; National Instruments, Austin, Texas, USA) and sampled at 1000 Hz.[18-20] Data were then collected and analyzed using a customized LabVIEW program with signals filtered with a 4^{th} order-low pass Butterworth filter and a cut-off frequency of 50-Hz. Total retraction tension of the position transducers equated to 23N, which was factored into all calculations. Each transducer was mounted to the top of the power cage and attached to the side of the barbell.[18-21] In accordance with previous research, 4 LPTs were utilized to quantify both vertical and horizontal movements from both sides of the barbell and establish a more accurate central displacement position.[18-21] The eccentric phase of each repetition commenced at zero displacement (standing) and was completed at maximal displacement (greatest descent) whereas the concentric phase began at maximal displacement and terminated at zero displacement. PV was the maximum value of the velocity data collected during the concentric phase of the repetition. MPV was determined as the average velocity of the concentric phase when acceleration of the barbell was greater than acceleration due to gravity.[22] MV was calculated as the average of the velocity data during the concentric contraction

Statistical Analyses

Reliability of PV, MPV and MV at each relative intensity (20, 40, 60, 80, 90, and 100% 1RM) was determined from the magnitude of the intra-class correlation coefficient (ICC), coefficient of variation (CV), and the Cohen's *d* effect size (ES). The present study considered the criterion variables highly reliable if they met the following three criteria: very high correlation (>0.70),[4,23] moderate CV (≥10%),[4,24] and a small ES (<0.60).[4,25] The smallest detectable difference (SDD), interpreted as the smallest measurement change that corresponds to a real difference beyond zero for PV, MPV and MV, was calculated as:

$$SDD = 1.96 \times \sqrt{2} \times SEM$$

where SEM is the standard error of the measurement,[26,27] which was also reported. Relationships between relative load and velocity (LVP) were studied by fitting linear regression, and second order polynomials to the data. The strength of the LVPs was assessed using Pearson product moment correlation (*r*) analysis. Fisher's r to z transformation analysis was used to ascertain significant correlation differences[28]: for PV, MPV and MV at each relative intensity between the three 1RM trials; between the LVPs developed from PV, MPV and MV; between the linear regression and second-order polynomial fitted LVPs. Confidence intervals were set at 95% for all reliability analyses. Data are reported as mean ± SD unless stated otherwise.

RESULTS

Group mean values over three 1RM trials for PV, MPV and MV at 20, 40, 60, 80, 90, and 100% 1RM are presented in Figure 1. Test-retest reliability was high for the group's 1RM assessments (ICC = 0.99; CV = 2.0%; SEM = 2.6 kg; ES = 0.05). An inverse linear relationship was observed with the movement velocities except for MPV and MV at 100% 1RM, which was substantially lower than the linear trend of the velocities between 20 and 90% 1RM.

PV was highly reliable at all relative intensities, but MPV and MV were highly reliable for all relative intensities except for 100% 1RM (Figure 2). The low reliability observed at 100% 1RM was due to low correlations (MPV: ICC = 0.66; MV: ICC = 0.55) and poor CVs (MPV: CV = 18.0%; MV: CV = 19.4%). As seen in Table 1, SDD values for PV were the highest of the three movement velocities. In addition, the SDD for MPV were slightly higher than MV.

The group means at 100% 1RM for PV, MPV and MV across the three trials were 0.84 ± 0.13 $m\cdot s^{-1}$, 0.26 ± 0.06 $m\cdot s^{-1}$ and 0.24 ± 0.05 $m\cdot s^{-1}$, respectively (Figure 3). The group mean movement velocities in trials 1 (PV: 0.84 ± 0.14 $m\cdot s^{-1}$; MPV: 0.26 ± 0.07 $m\cdot s^{-1}$; MV: 0.24 ± 0.07 $m\cdot s^{-1}$), 2 (PV: 0.82 ± 0.14 $m\cdot s^{-1}$; MPV: 0.26 ± 0.07 $m\cdot s^{-1}$; MV: 0.24 ± 0.07 $m\cdot s^{-1}$), and 3 (PV: 0.83 ± 0.13 $m\cdot s^{-1}$; MPV: 0.25 ± 0.06 $m\cdot s^{-1}$; MV: 0.24 ± 0.04 $m\cdot s^{-1}$) were almost identical at 100% 1RM (Figure 3), yet the individual subject variation ranges between the three trials was moderate for PV (-10.8 to 12.2%) and extremely large for MPV (-34.8 to 41.0%) and MV (-36.3 to 32.5%).

Based on the reliability results from Figure 2 we created LVPs from relative intensities that were highly reliable. The LVPs included PV from 20-100% 1RM, while MPV and MV were created utilizing 20-90% 1RM (Figure 4). Once the LVPs were created we then fitted the velocity data with linear and second-order polynomial fits to determine if the added complexity was necessary to improve the correlations (accuracy) of the LVPs (Figure 4). Correlation ranges for the individualized linear regression LVPs (PV: r = 0.89 to 0.99; MPV: r = 0.90 to 0.99; MV: r = 0.90 and 0.99) and individualized polynomial regression LVPs (PV: r = 0.89 to 0.99; MPV: r = 0.90 to 0.99; MV: r = 0.91 to 0.99) were almost perfect. The Fisher r to z transformation revealed no significant differences for the correlations between the individualized linear and polynomial regression fits in trials 1, 2, or 3 for PV, MPV and MV. Furthermore, there were no significant differences between the correlations for the LVPs derived from the three different movement velocities.

DISCUSSION

The results of the present study advocate that PV was highly reliable at all six relative intensities tested including 100% 1RM. Similarly, MPV and MV were highly reliable at 20, 40, 60, 80, and 90% but not 100% 1RM. This suggests that all three-movement velocity types are acceptable to monitor changes in movement velocity (fatigue monitoring) for the free-weight squat exercise; however, a coach should not incorporate the movement velocity at 100% 1RM if the LVPs are created from MPV or MV. Moreover, there was no difference between the correlations of LVPs using linear regression or second-order polynomial fits.

Interestingly, the 100% 1RM values of MV (0.24 ± 0.05 $m \cdot s^{-1}$) reported in the present study are in line with the findings of Zourdos et al[29] (0.24 ± 0.04 $m \cdot s^{-1}$) who also assessed the full depth back squat. In addition, the poor reliability of MV at 100% 1RM observed in the present study (ICC = 0.55; CV = 19.4%; SEM = 0.04 $m \cdot s^{-1}$) is also in accordance with recent research (ICC = 0.42; CV = 22.5%; SEM = 0.05 $m \cdot s^{-1}$) for the free-weight back squat exercise reported elsewhere.[4] Research by Gonzalez-Badillo and Sanchez-Medina[6] exploring the use of

LVPs did not report the reliability of MPV at baseline, yet they found no statistically significant change in MPV (ICC = 0.81 - 0.91; CV = 0.0 - 3.6%) at 5% incremental loads between 30 and 100% 1RM when 56-subjects performed a bench press LVP before (trial 1) and after (trial 2) six weeks of upper body resistance training. They concluded that despite an average increase of 9.3% in maximal strength for their participant's over 6-weeks of training from trial 1 to trial 2, MPV was stable at each relative intensity.[6] To our knowledge, no studies have verified if this phenomenon is true for PV or MV. Therefore, even though PV and MV are reliable in the present study, future studies should establish whether PV and MV remain stable through the relative intensity spectrum if maximal strength changes.

The poor reliability observed in the current study for MPV and MV at 100% 1RM is likely due to small horizontal movements that can accompany the predominant vertical bar path in the free-weight back squat,[14] as well as the inclusion of the SSC for the concentric contraction.[30] As a consequence, previous studies assessing LVPs to monitor fatigue have implemented the Smith machine and a pause or concentric only contraction to minimize the measurement error of concentric movement velocity in their LVPs and 1RM assessments.[6,10] Despite this, the present study utilized the free-weight back squat and demonstrated that MPV and MV were reliable at all relative intensities except at 100% 1RM. Therefore movement velocity at 1RM should not be included with these movement velocities that make up the LVP. Importantly, exercises incorporating the SSC are known to result in greater force production than concentric only contractions.[15] Therefore, the methodology used by previous research may provide limited ecological validity for a back squat exercise, which athletes typically utilize in a free-weight manner with the SSC in order to maximize force production and enhance performance tasks like jumping. Furthermore, free-weight 1RM assessments are likely to produce higher 1RM loads than pause or concentric only 1RM assessments since greater force is produced in exercises utilizing the SSC compared with only concentric contractions.[15] As a consequence, training adaptation could be compromised if free-weight exercises are prescribed from pause or concentric only 1RM assessments.

To our knowledge, the present study is the first to report the reliability of PV, MPV and MV through the relative intensity spectrum, and subsequently utilize the reliable relative loads to develop LVPs in a free-weight exercise for strength-trained individuals in a non-fatigued state. Typically, PV is utilized to monitor impulsive type resistance training exercises such as the countermovement jump or bench throw, whereas MV is thought to better represent non-aerial movements like the squat or bench press through the entire concentric phase. Sanchez-Medina et al.[22] have suggested that MPV is more appropriate than MV at light and medium loads during non-aerial movements such as the squat because MV underestimates movement velocity when individuals decelerate the barbell at the top of the lift to maintain balance. Our results showed there were no significant differences between the correlations of the LVPs derived from PV, MPV, or MV. Furthermore, there were no significant differences between the correlations of the LVPs fitted with linear regression or second order polynomials for all three-movement velocities (Figure-4). This suggests that PV, MPV and MV are all suitable to develop LVPs if movement velocities at reliable relative loads are chosen for the profiles. Furthermore, the added complexity of fitting a second order polynomial to the LVP is unnecessary for the free-weight back squat. However, when a coach is selecting which movement velocity to employ to develop a LVP, they should be cognizant of the SDD (Table-1) associated with the different movement velocities when adjusting sessional training loads.

A recent study by Conceição et al.[10] tested 15-male track and field athletes and developed LVPs which were derived from PV and MPV at 5% incremental loads from 15 to 100% 1RM, for the incline machine leg press, full squat and half squat exercises performed on a Smith machine. They anecdotally suggested PV and MPV were stable for all exercises but did not report any reliability findings as the subjects were only tested once for each exercise.

Therefore it is difficult to ascertain if the LVPs derived from the study of Conceição et al.[10] were stable and could be used to monitor fatigue (declines in movement velocity). In addition, Conceição et al.[10] provided a group mean equation for each exercise which individuals can use to determine their relative intensity for a given movement velocity. Although a generalized LVP equation is helpful and has some validity, the present study suggests that LVPs are highly individualized. For example, although movement velocity is highly reliable, the ranges of measurements for PV at 20 (1.62 - 2.30m·s^{-1}), 40 (1.36 - 1.96m·s^{-1}), 60 (1.09 - 1.60m·s^{-1}), 80 (0.84 - 1.29m·s^{-1}), 90 (0.70 - 1.12m·s^{-1}), and 100% 1RM (0.58 - 0.91m·s^{-1}) were vastly different between individuals. As a consequence, coaches should create individualized LVPs for each athlete to improve the accuracy of monitoring changes in movement velocity and modifying training loads. The concept of individualizing training to enhance performance is in accordance with Jiménez-Reyes, Samozino[31] who individualized force-velocity profiles to maximize adaptations in jump performance.

Commonly, coaches monitor fatigue by tracking reductions in peak force using maximal isometric force assessments (isometric mid-thigh pull) or PV with ballistic power tests (countermovement jump).[32,33] These tests are proven to be valid and reliable but these assessments do not precisely identify how training loads can be modified for a specific exercise such as the squat. The present study has demonstrated that PV, MPV or MV can all be used to modify training load in the free-weight back squat if consistent barbell displacement and maximal concentric effort are provided. Therefore, coaches can use movement velocity as an accurate monitoring tool to determine an athlete's level of effort and adjust training load in a specific exercise if movement velocity targets are not met.

The results from the present study and previous research investigating LVPs for modifying the load in training sessions are encouraging. However, some caution should be taken from the results particularly in the practical setting due to the specificity of the associated methodology of the testing assessments. For example, the findings from the present study do not necessarily transfer to other exercises commonly utilized by athletes. Future studies should seek to investigate load-velocity profiling for each exercise performed by the athlete in order to modify lifting loads during training. In addition, if an individual intends to develop a LVP for the back squat exercise using MPV or MV, training velocities derived from the load-velocity relationship at relative loads greater than 90% 1RM may not be reliable. Therefore, LVPs utilizing MPV and MV could be problematic when training at near maximal relative intensities in the free-weight back squat. Crucially, the results obtained from this study are representative of a population who could lift between 150 to 240% of their body mass for at least one repetition. If someone were to employ load-velocity profiling as part of their training paradigm they would need to collect this data on their athlete population as part of their athlete testing/monitoring program. As discussed previously, if an athlete was to employ velocity based training methods, their own individualized LVP should be obtained. In addition, if the movement velocity is outside the range of the SDD (Table-1), a coach could modify the training load to achieve the requisite velocity from the LVP. However, further research is needed to further verify if this is an effective method of training.

CONCLUSIONS

In summary, PV, MPV and MV are reliable and can be used to develop LVPs in the full depth free-weight back squat. This suggests that movement velocity could be monitored in training and the sessional training loads may be adjusted according to daily readiness. Interestingly, it appears unnecessary to employ the added complexity of fitting second-order polynomials, compared to linear regression, to improve the accuracy of the LVPs. Furthermore, since there were no significant differences between the LVPs developed from the three movement velocities, we would suggest the utilization of PV, MPV or MV would be appropriate to develop LVPs with linear regression fits.

Practical Applications

The present study suggests that if practitioners are to utilize LVPs to train competent athletes in a free-weight back squat, their athlete should: (1) perform a 1RM assessment; (2) conduct an individualized LVP using $PV_{20\text{-}100\%}$, $MPV_{20\text{-}90\%}$, or $MV_{20\text{-}90\%}$; (3) employ a linear regression equation and convert a relative intensity table (convert the %1RM to velocity) into a movement velocity (PV, MPV, or MV) table; (4) modify training loads based on the SDD of their athlete at the required training load.

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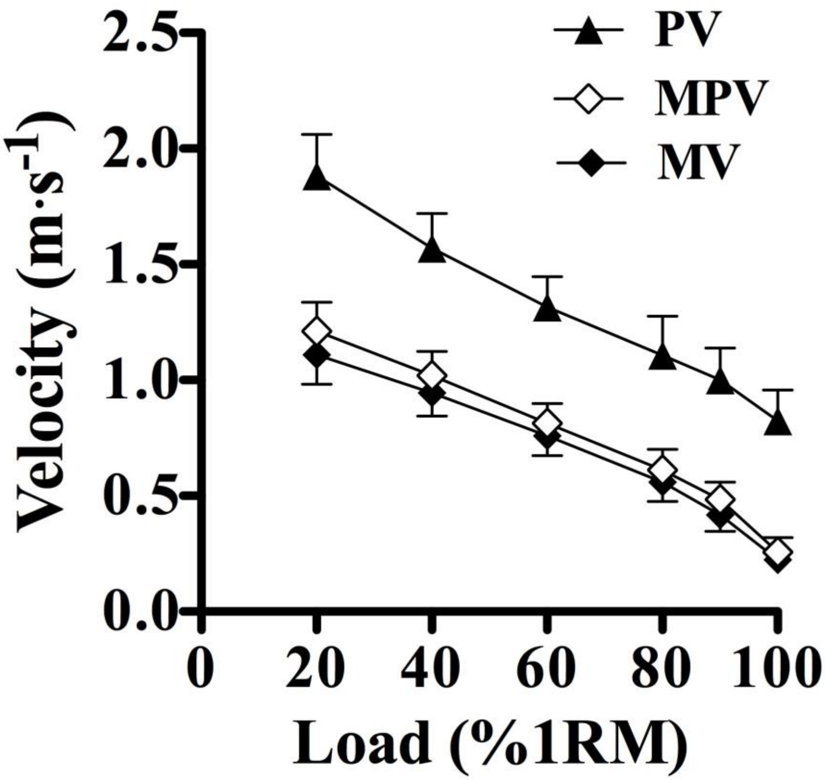

Figure 1: Group mean (±SD) values from three 1RM trials for peak velocity (PB), mean propulsive velocity (MPG), and mean velocity (MV) at 20, 40, 60, 80, 80, and 100% 1RM load.

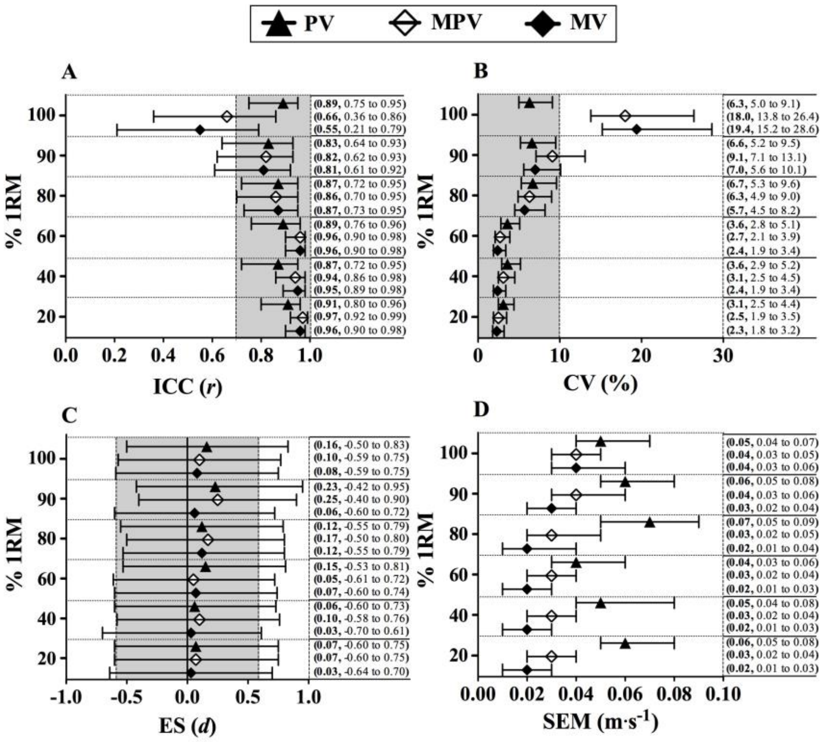

Figure 2: Reliability of PB peak velocity, MPV mean propulsive velocity, and MV mean velocity in the back squat at 20, 40, 60, 80, 90, and 100% 1RM. Forest plots displaying: ICC intraclass correlation coefficient (A), CV coefficient of variation (B), ES effect size estimates (C), and SEM standard error of the estimate (D). Area shaded in grey indicates the zone of acceptable reliability. Error bars indicate 95% confidence limits. Right Y axes contain the mean and ±95% confidence limits.

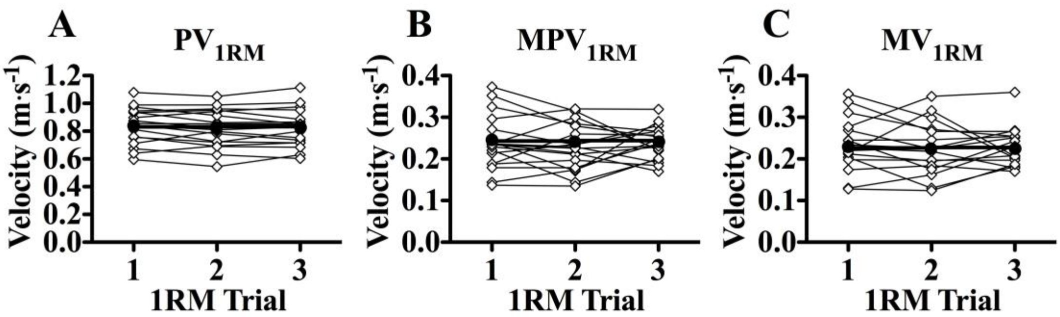

Figure 3: Individual variation and the group mean of PV peak velocity (A), MPV mean propulsive velocity (B), and MV mean velocity (C) at 100% 1RM for trials 1, 2, and 3. The black circles indicate the group mean for the relevant 1RM trial.

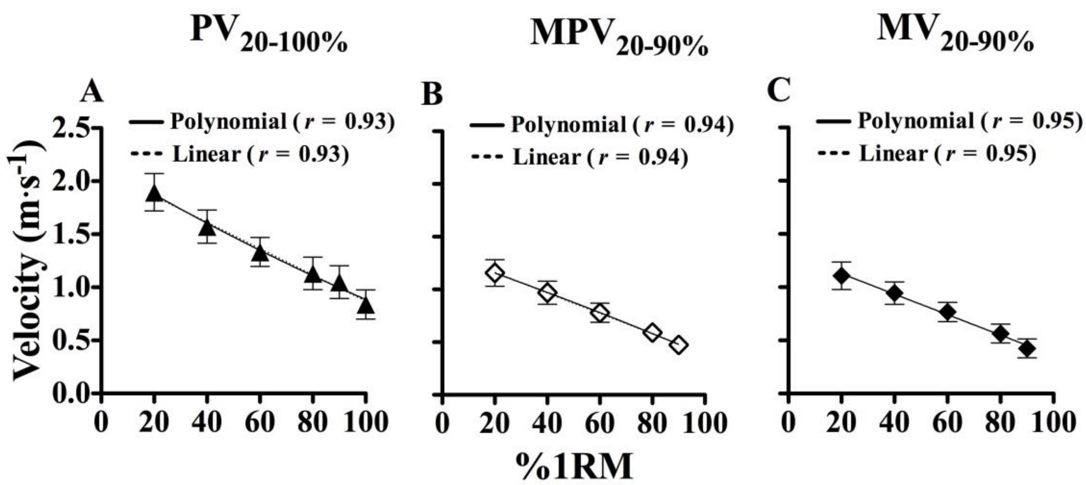

Figure 4: Load-velocity profiles obtained from group mean data (±SD) using a second order polynomial fit and a linear regression fit between relative load and (A) peak velocity from 20-100% 1RM (PV20-100%), (B) mean propulsive velocity from 20-90% 1RM (MPV20-90%), and (C) mean velocity from 20-90% 1RM (MV20-90%).

Table 1. Recommendations for the smallest detectable difference of peak velocity (PV), mean propulsive velocity (MPV), and mean velocity (MV) at 20, 40, 60, 80, 90, and 100% 1RM.

%1RM	PV ($m \cdot s^{-1}$)	MPV ($m \cdot s^{-1}$)	MV ($m \cdot s^{-1}$)
20	0.17	0.08	0.06
40	0.14	0.08	0.06
60	0.11	0.08	0.06
80	0.19	0.08	0.06
90	0.17	0.11	0.08
100	0.14	*0.11	*0.11

Note: * did not meet reliability criteria (ICC > 0.70, CV <10%, ES < 0.59).